US010847867B2

(12) United States Patent
Dai

(10) Patent No.: US 10,847,867 B2
(45) Date of Patent: Nov. 24, 2020

(54) **WINDOW ASSEMBLY WITH HEATING AND ANTENNA FUNCTIONS**

(71) Applicant: **David Dai**, Novi, MI (US)

(72) Inventor: **David Dai**, Novi, MI (US)

(73) Assignee: **Pittsburgh Glass Works, LLC**, Pittsburgh, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 155 days.

(21) Appl. No.: **16/292,691**

(22) Filed: **Mar. 5, 2019**

(65) **Prior Publication Data**

US 2019/0273302 A1 Sep. 5, 2019

Related U.S. Application Data

(60) Provisional application No. 62/638,504, filed on Mar. 5, 2018.

(51) **Int. Cl.**

H01Q 1/12	(2006.01)
H01Q 13/10	(2006.01)
H05B 3/84	(2006.01)
H01Q 1/32	(2006.01)
H01Q 5/30	(2015.01)

(52) **U.S. Cl.**

CPC ***H01Q 1/1278*** (2013.01); ***H01Q 1/325*** (2013.01); ***H01Q 5/30*** (2015.01); ***H01Q 13/10*** (2013.01); ***H05B 3/84*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,655,545	A	4/1972	Gillery et al.
3,962,488	A	6/1976	Gillery
4,707,700	A	11/1987	Nagy
4,768,037	A	8/1988	Inaba et al.
4,849,766	A	7/1989	Inaba et al.
4,864,316	A	9/1989	Kaoru et al.
4,898,789	A	2/1990	Finley
5,355,144	A	10/1994	Walton et al.
5,670,966	A	9/1997	Dishart et al.
5,898,407	A	4/1999	Paulus et al.

(Continued)

FOREIGN PATENT DOCUMENTS

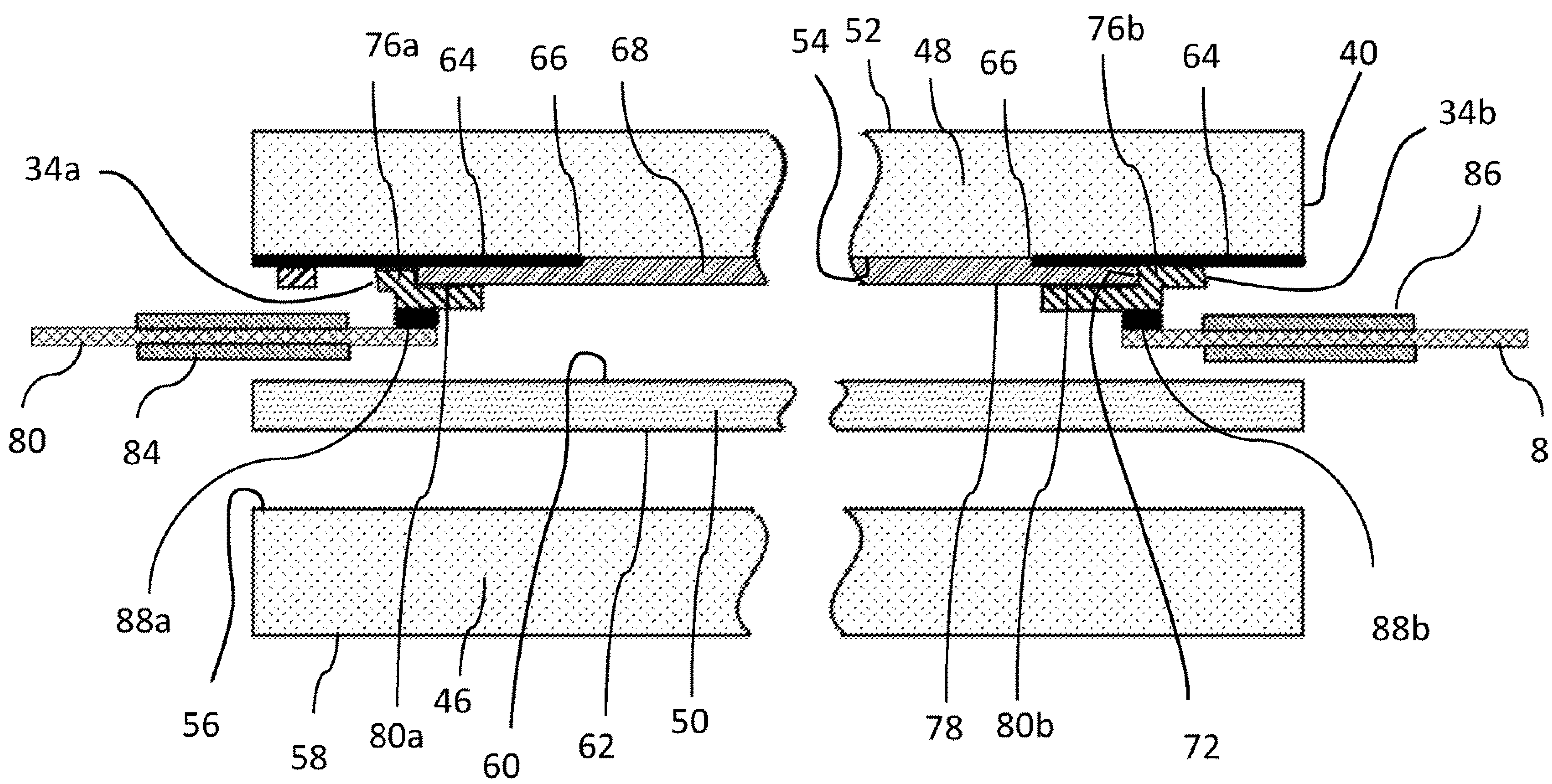
DE	102012008033	A1	11/2012

Primary Examiner — Amy Cohen Johnson
Assistant Examiner — James H Cho
(74) *Attorney, Agent, or Firm* — Dentons Cohen & Grigsby P.C.

(57) **ABSTRACT**

A vehicle glazing with a slot antenna between the vehicle portal and the peripheral edge of an IR reflective coating that includes a heating bus over the coating edge. The antenna slot may be fed directly by a voltage probe or a coupled coplanar line at a position to excite both fundamental and higher order modes for multiband antenna applications. A portion of the IR reflective coating may overlay the window frame at null positions of first higher order mode to tune the slot antenna to higher frequencies. Slot antenna resonant frequency may also be moved higher by separating the IR reflective coating into two coating panel with the lower coating panel connected to electrical ground by capacitive coupling. Multiple antennas can be fed at different locations for multiband applications and diversity antenna systems.

36 Claims, 11 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,764,239	B2	7/2010	Baranski	
9,337,525	B2	5/2016	Dai	
10,638,548	B2 *	4/2020	Kagaya	H05B 3/84
2009/0128431	A1 *	5/2009	Martin	B32B 17/10376 343/713
2015/0222006	A1 *	8/2015	Dai	H01Q 13/10 343/712
2016/0134013	A1 *	5/2016	Suenaga	H01Q 7/00 343/711
2017/0317399	A1	11/2017	Droste et al.	

* cited by examiner

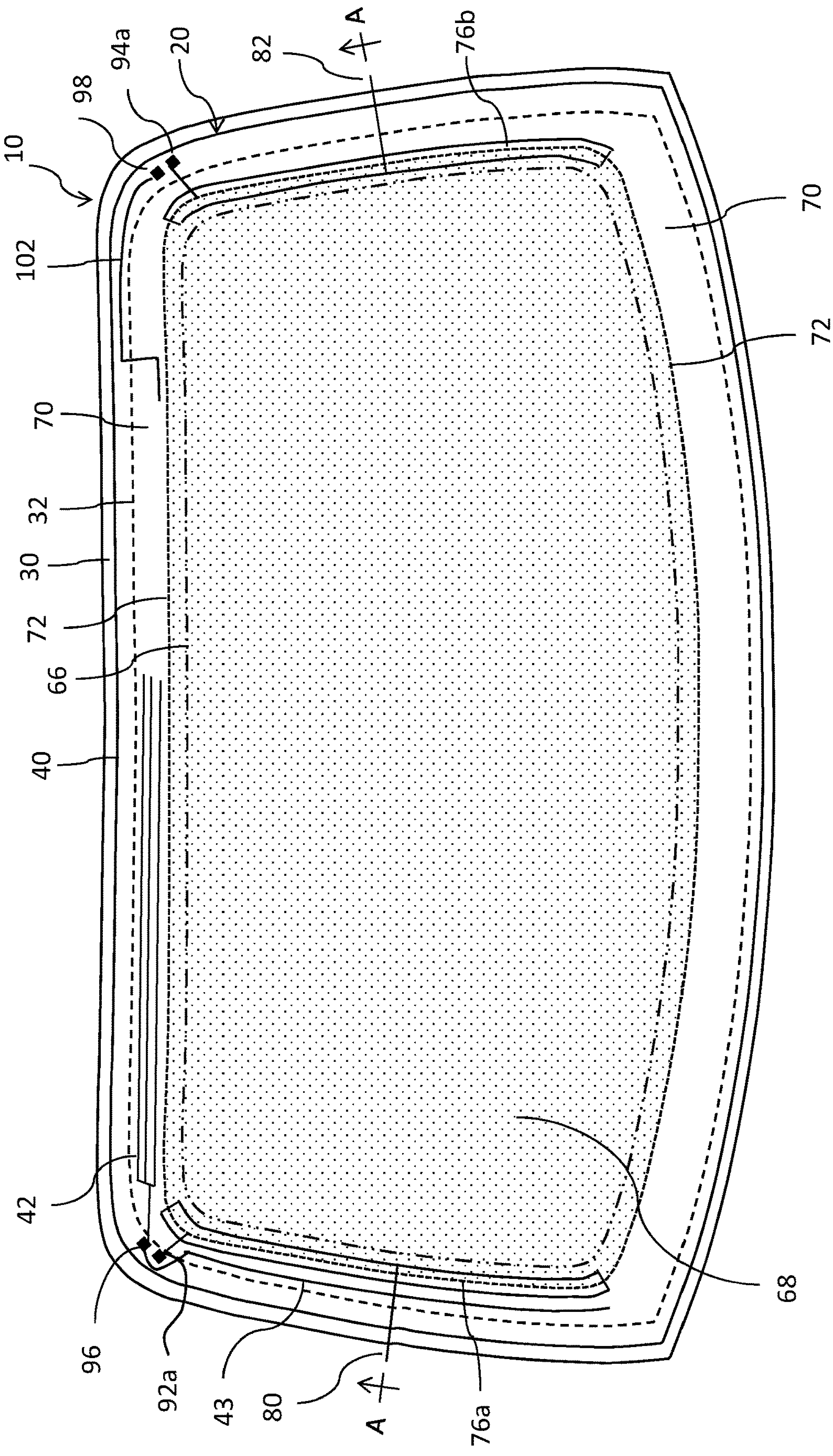

A
82
76b
20
94a
98
10
102
70
72
70
32
30
72
66
40
42
68
96
92a
43
80
A
76a

FIG. 1

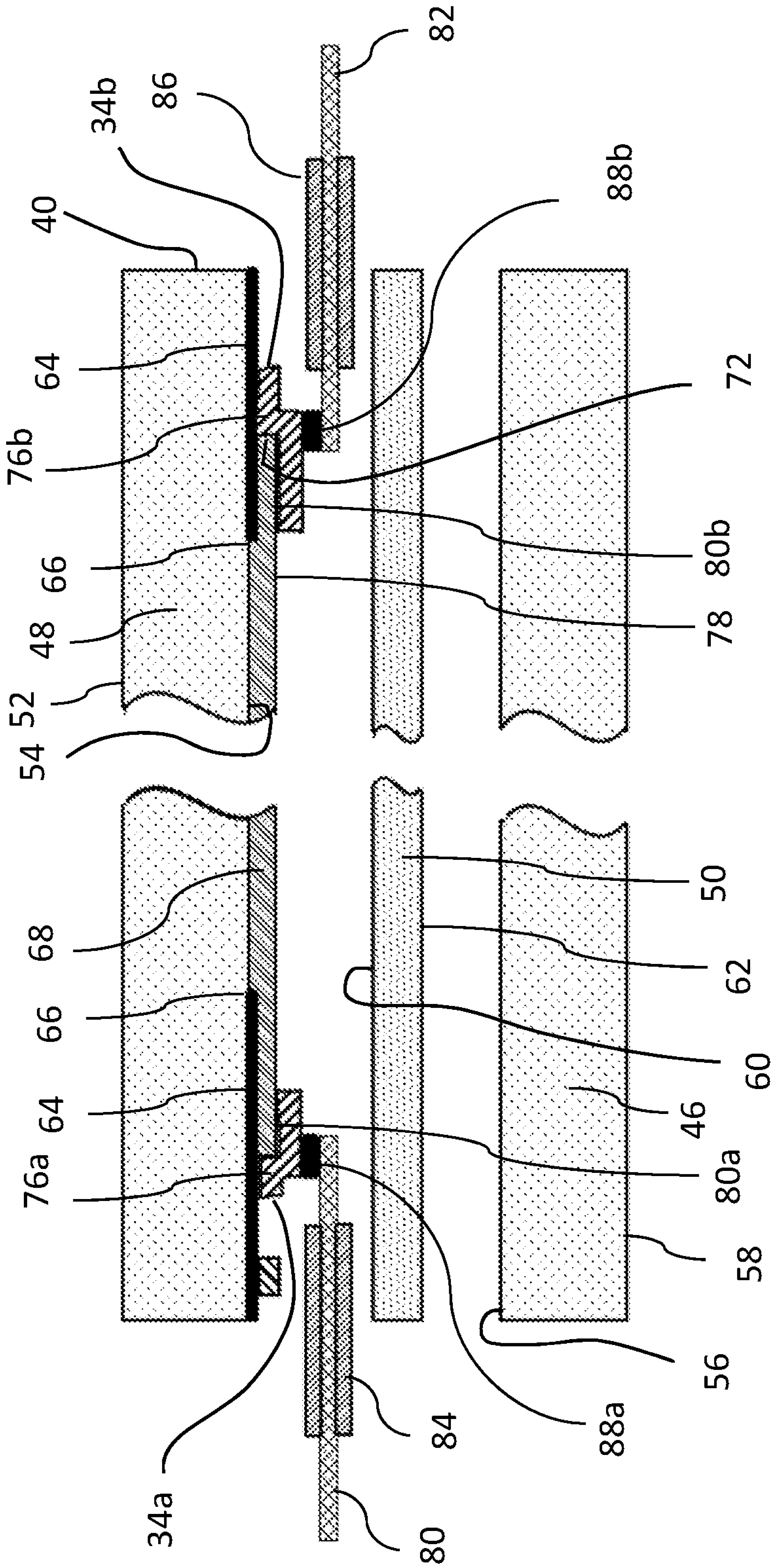

82
86
34b
40
88b
64
72
76b
80b
66
78
48
52
54
50
68
62
66
60
64
46
76a
80a
58
56
84
88a
34a
80

FIG. 2

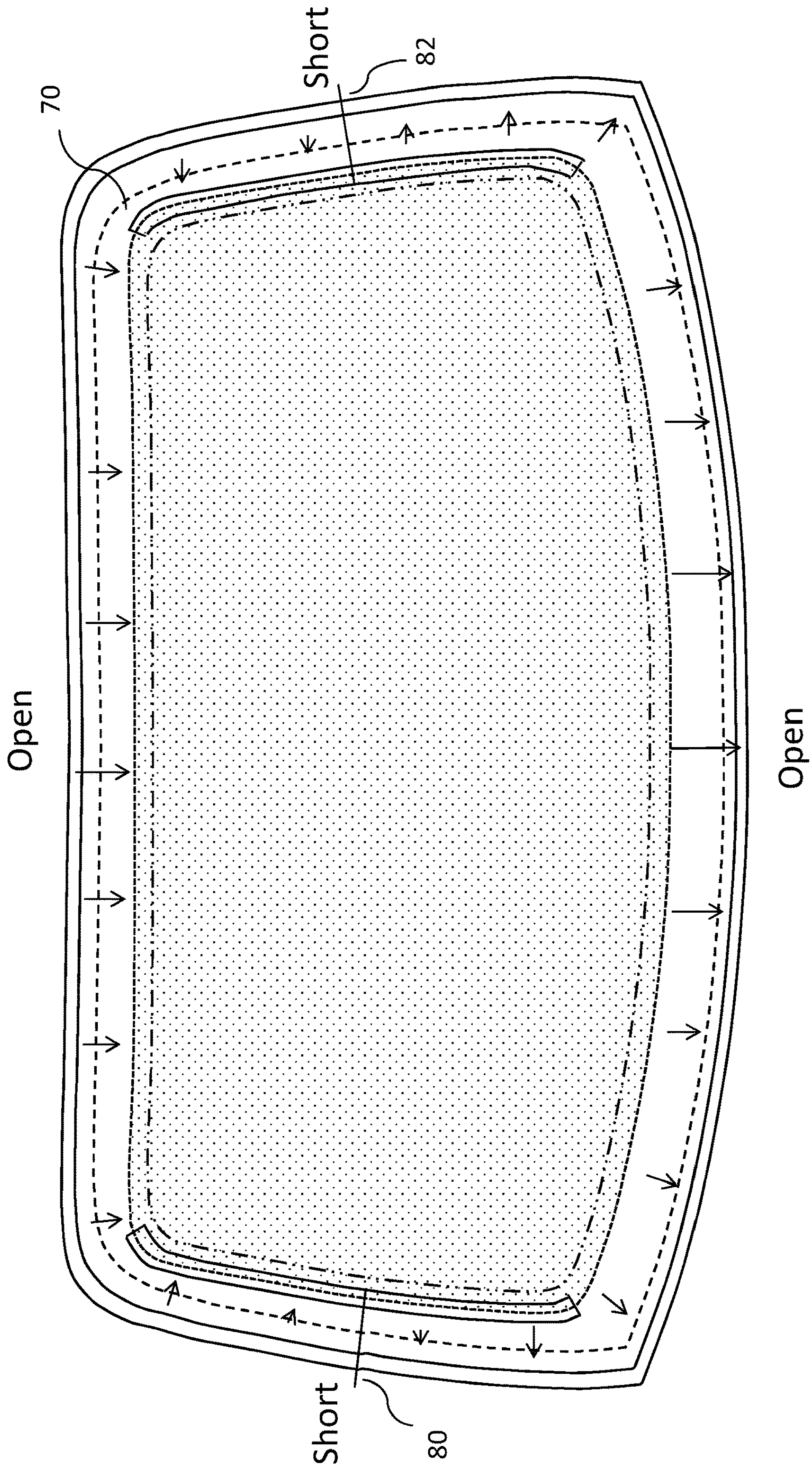


FIG. 3

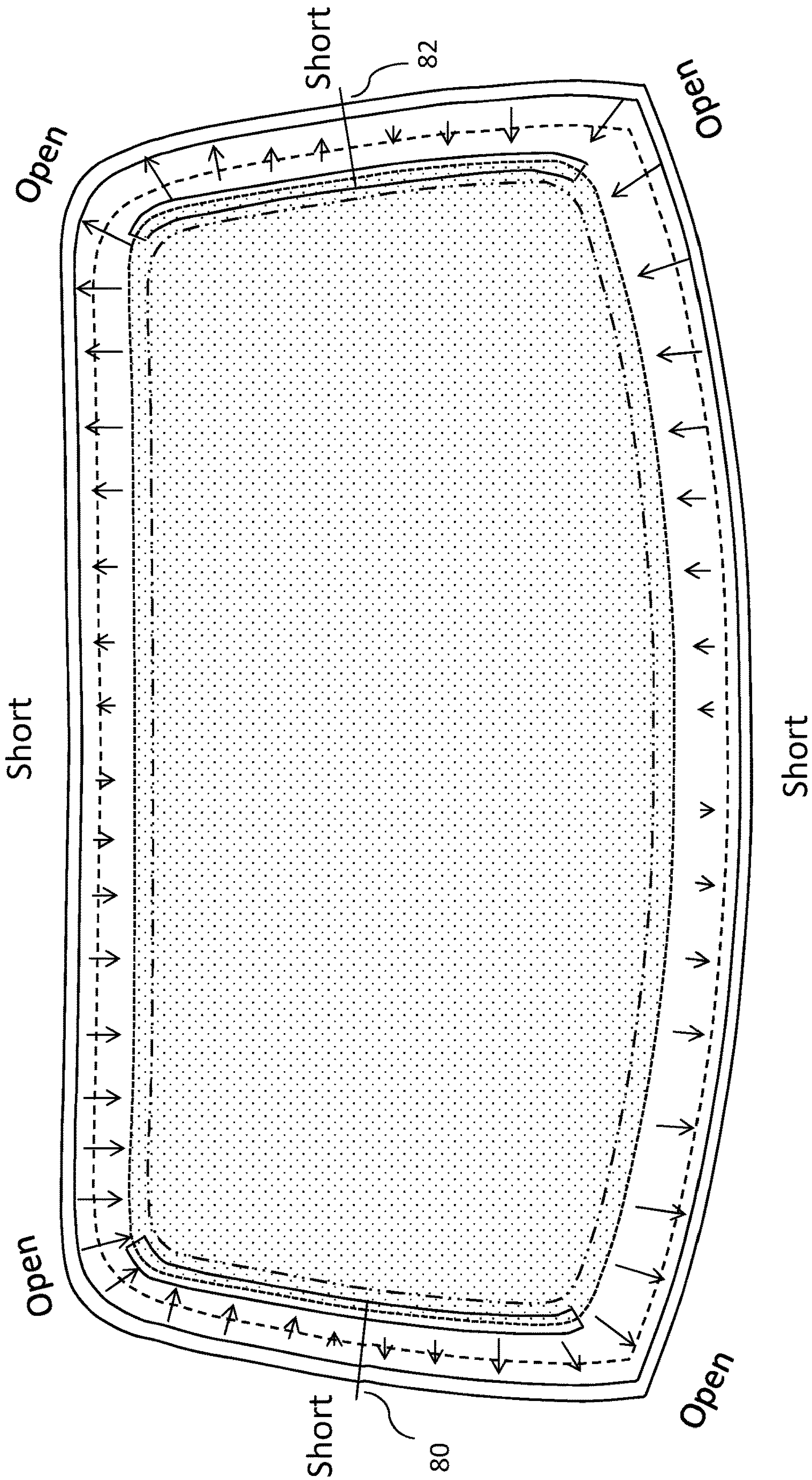


FIG. 4

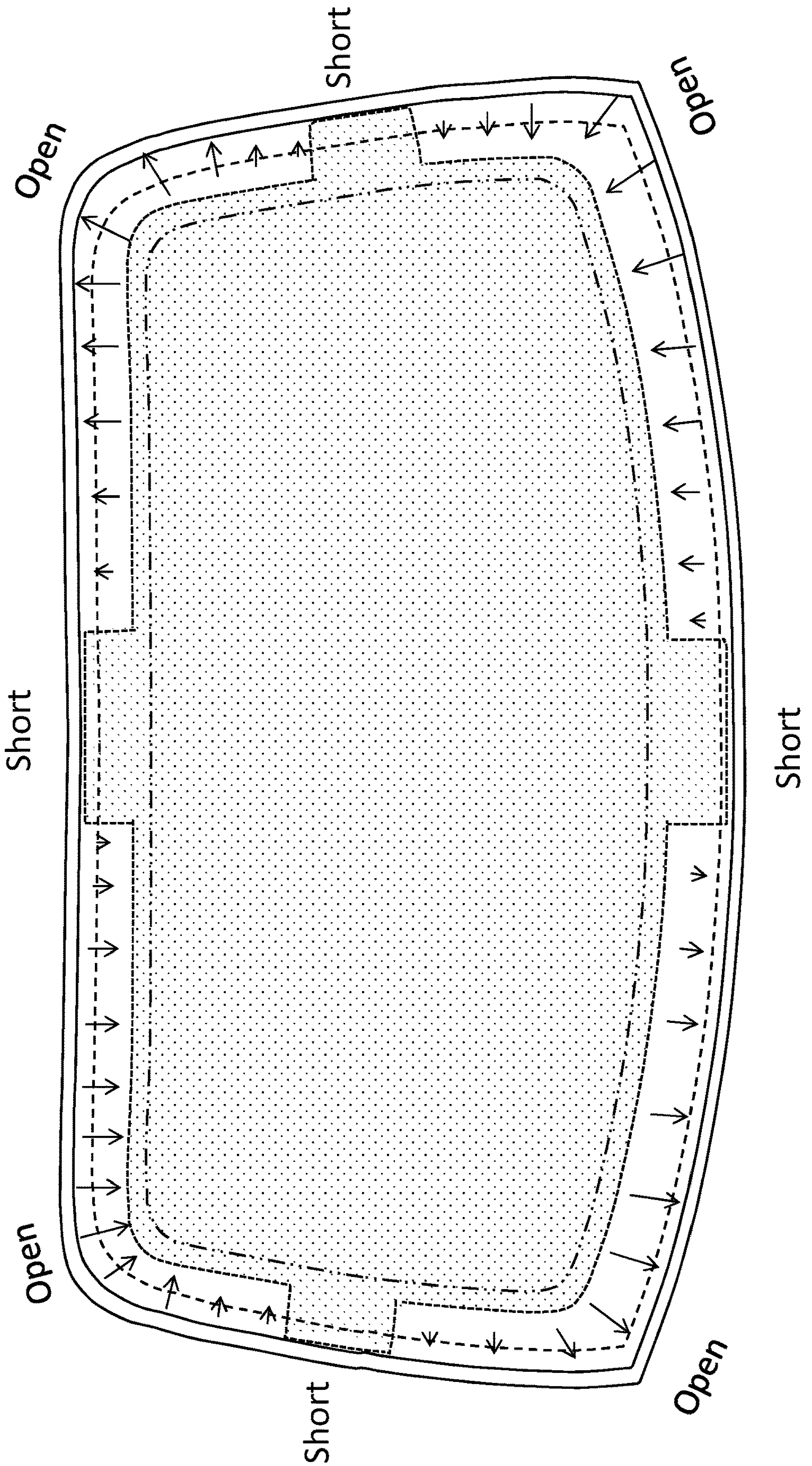


FIG. 5

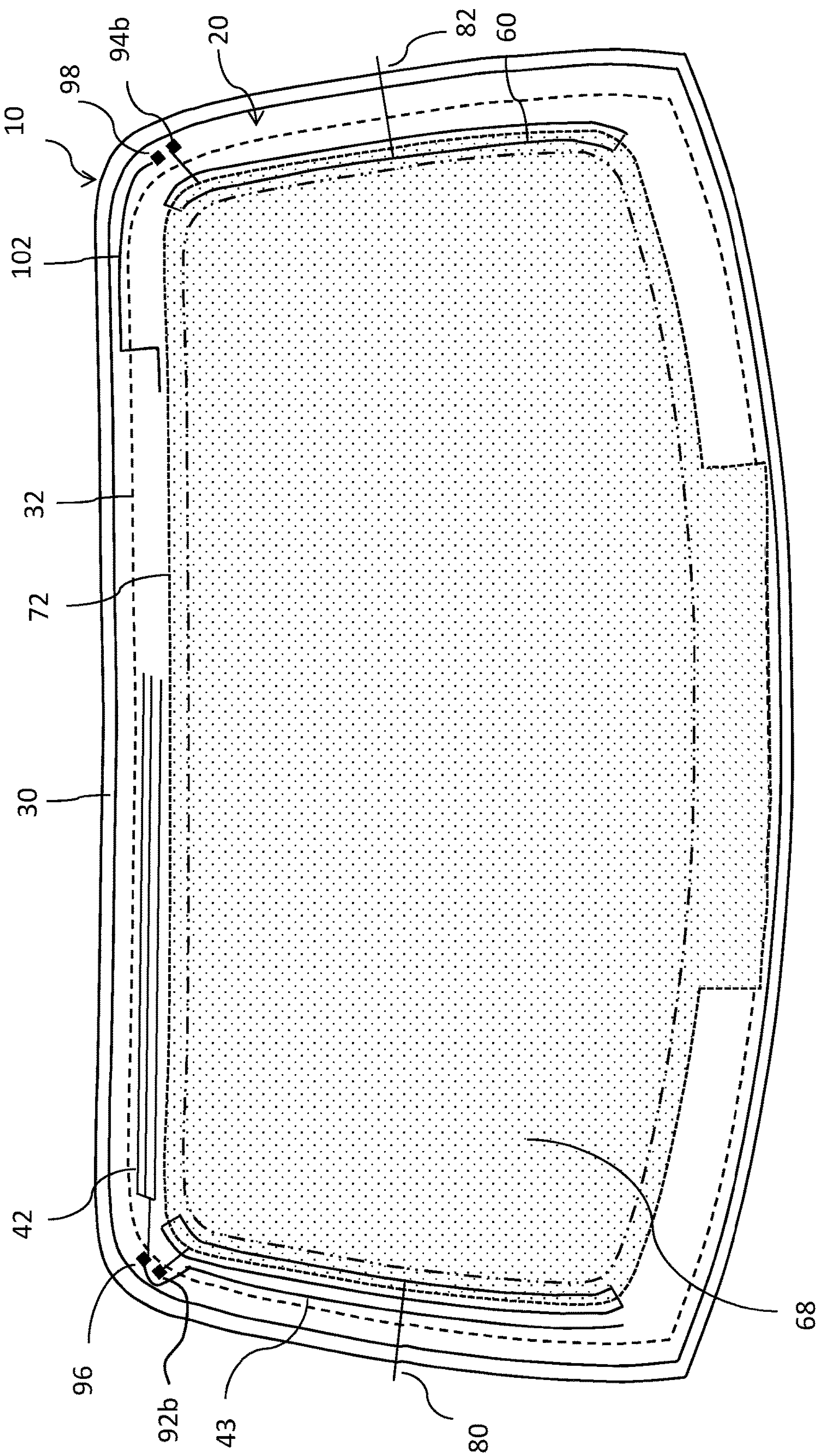


FIG. 6

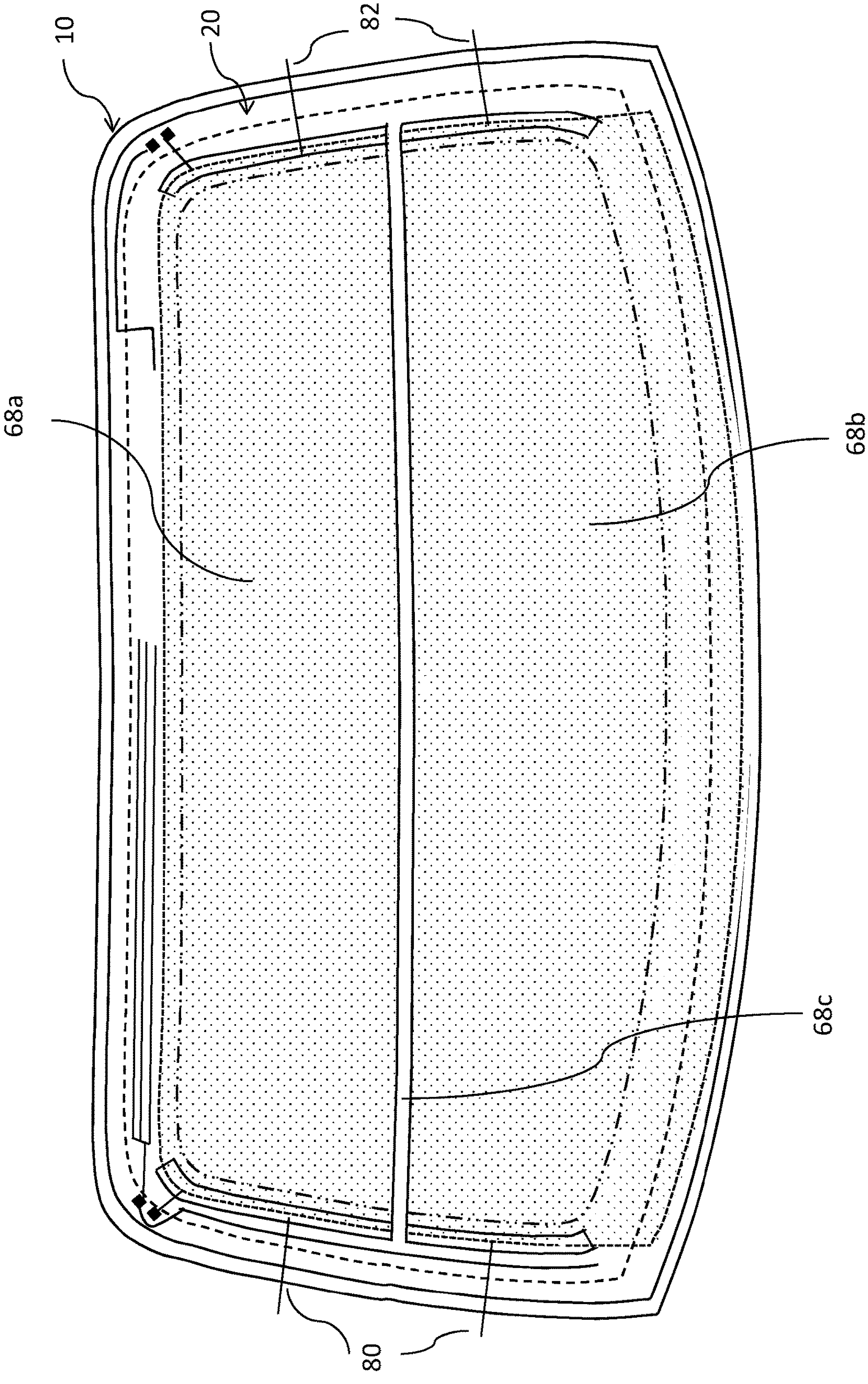


FIG. 7

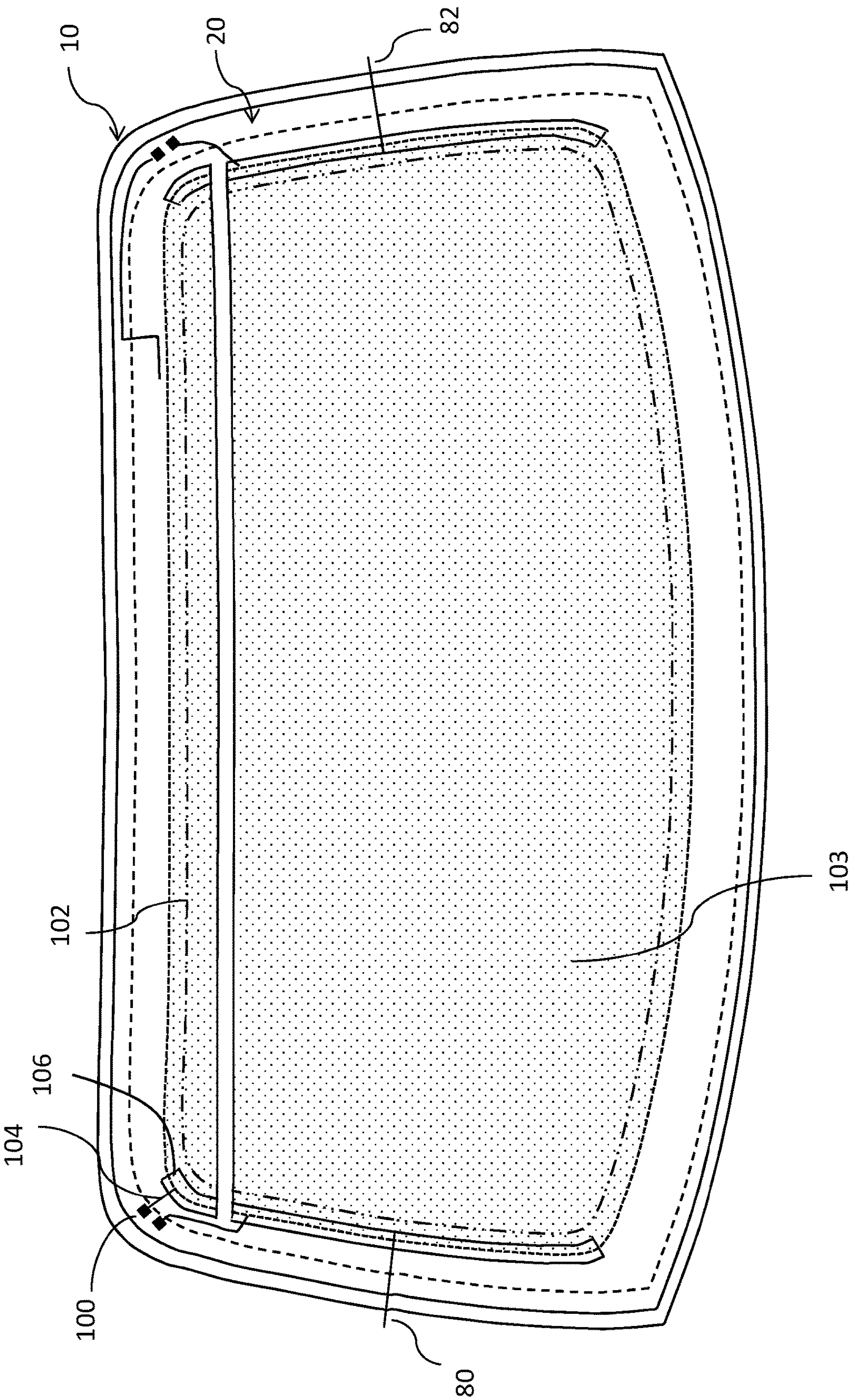


FIG. 8

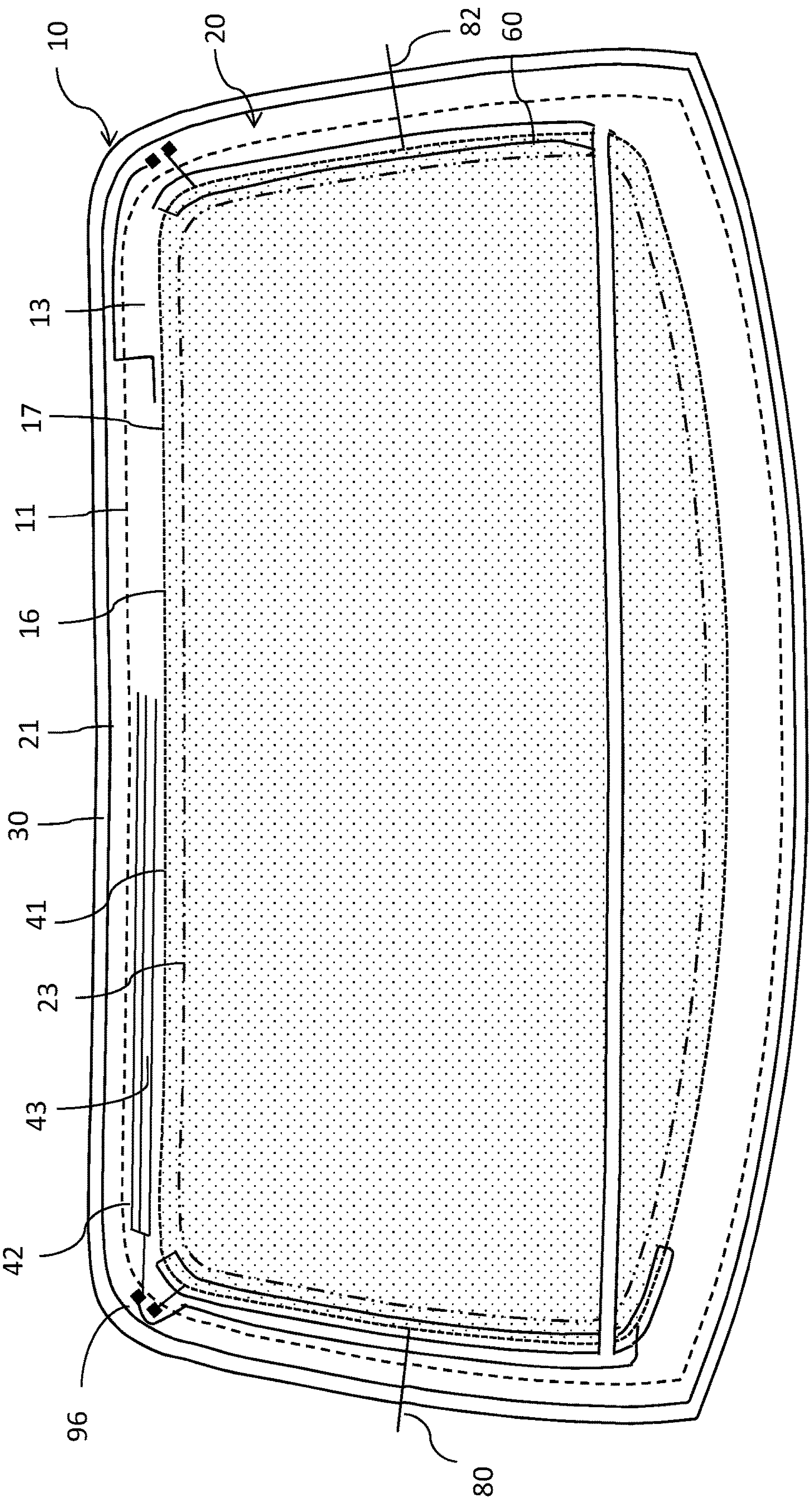


FIG. 9

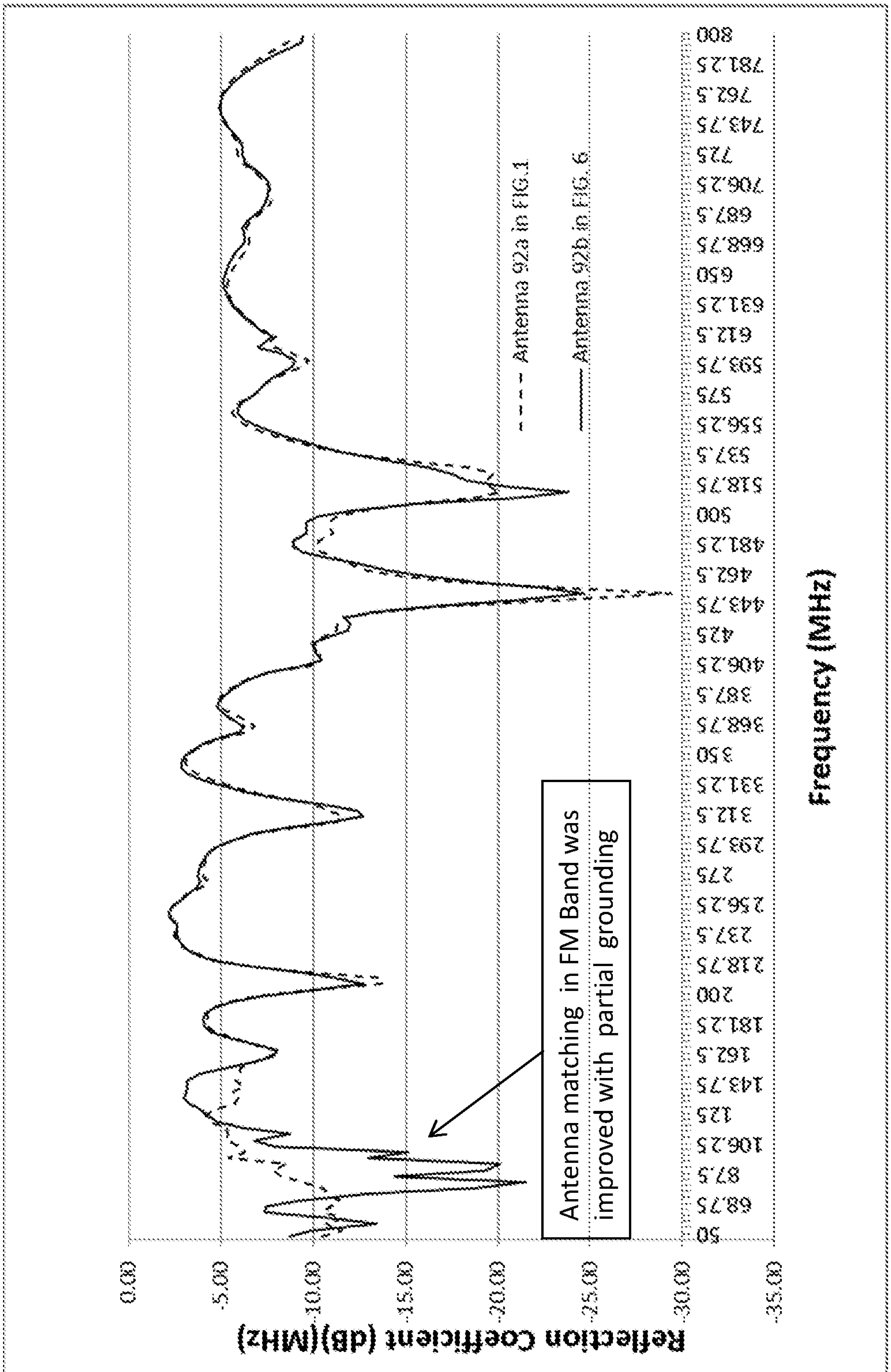

Reflection Coefficient (dB)(MHz)
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
Frequency (MHz)
50
68.75
87.5
106.25
125
143.75
162.5
181.25
200
218.75
237.5
256.25
275
293.75
312.5
331.25
350
368.75
387.5
406.25
425
443.75
462.5
481.25
500
518.75
537.5
556.25
575
593.75
612.5
631.25
650
668.75
687.5
706.25
725
743.75
762.5
781.25
800
Antenna 92a in FIG.1
Antenna 92b in FIG. 6
Antenna matching in FM Band was improved with partial grounding

FIG. 10

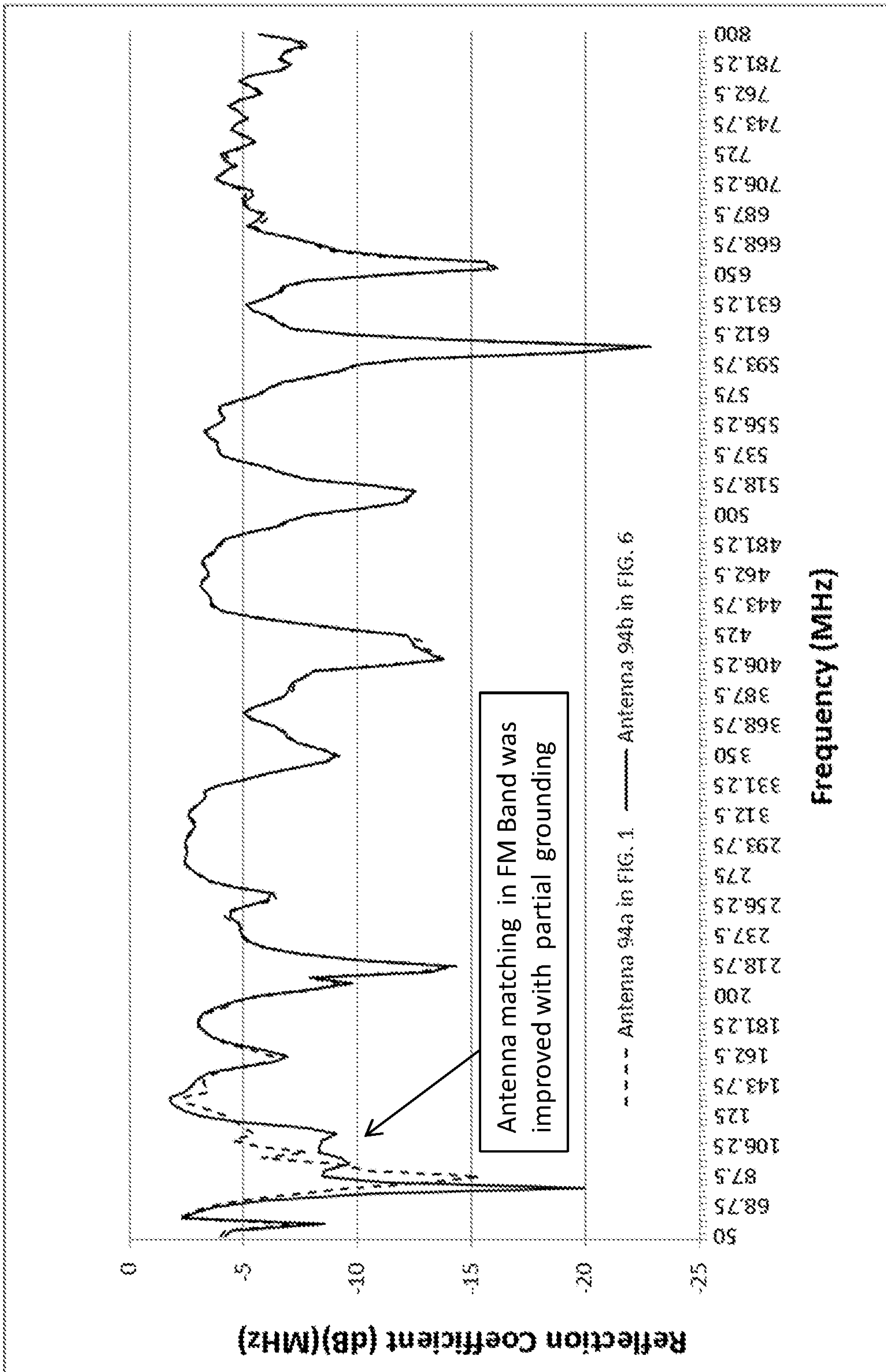

Antenna matching in FM Band was improved with partial grounding
Antenna 94a in FIG. 1
Antenna 94b in FIG. 6
Frequency (MHz)
Reflection Coefficient (dB)(MHz)
0
-5
-10
-15
-20
-25
50
68.75
87.5
106.25
125
143.75
162.5
181.25
200
218.75
237.5
256.25
275
293.75
312.5
331.25
350
368.75
387.5
406.25
425
443.75
462.5
481.25
500
518.75
537.5
556.25
575
593.75
612.5
631.25
650
668.75
687.5
706.25
725
743.75
762.5
781.25
800

FIG. 11

WINDOW ASSEMBLY WITH HEATING AND ANTENNA FUNCTIONS

TECHNICAL FIELD

The present invention relates generally to vehicle antennas and, more particularly, to an antenna formed in association with a glazing having an electrically heatable conductive coating.

BACKGROUND OF THE INVENTION

In recent years, window glazings with additional functions such as solar load reduction have become more popular in automotive vehicles and architectural structures. In order to reduce heat build-up in the interior of a vehicle or building, the glazing can be coated with a solar control film that reflects solar energy. Such solar control films are usually transparent, electrically conductive films. In addition, transparent, metallic film on window glazings may be used on vehicle windows in order to enable a flow of DC current across the window when applying a DC voltage to the metallic coating. Such embodiments are typically used to defrost (i.e., melt snow and ice) or defog the window.

In automotive transparencies, such as windshields and back windows, antennas for the reception and/or transmission of radio frequency waves such as AM, FM, TV, DAB, RKE, etc. are often mounted on or incorporated into the transparency. These antennas can be formed by printing conductive lines such as silver or copper onto the transparency or by metal wires or strips attached to the transparency. One of the consequences of using metallic coated windows is that they can attenuate the propagation of RF signals through the window. As a result, wireless communication into and out of buildings, vehicles, and other structures that use metallic coated windows to reduce heat load can be restricted. One solution for applications in which the metallic coating interferes with the propagation of signals through the window has been to remove a portion of the metallic coating that interferes with the antennas. Removal of the coating facilitates the transmission of RF signals through the portion of the window where the coating is removed. However, removal of the metallic coating tends to increase solar energy transmission into the interior of the vehicle, which can increase the vehicle temperature. Also, in some cases, removal of the metallic coating may break the DC current flow through the glazing and create non-heating zones on the glazing.

Some prior constructions have integrated antennas with the window. Antennas have been proposed that employ quarter wavelength or half wavelength antennas or slot antennas formed between the metal frame of a window and a conductive transparent film or coating. For example, U.S. Pat. Nos. 4,849,766; 4,768,037; 5,670,966; and 4,864,316 illustrate a variety of antenna shapes that are formed by a thin film on a vehicle window. U.S. Pat. Nos. 4,707,700; 5,355,144; 5,898,407; 7,764,239; and 9,337,525 disclose different slot antenna structures.

European patent application DE 10 2012 008 033 A1 discloses a motor vehicle window that is partially heatable with a heating device and that utilizes a portion of non-heated window as an antenna for transmitting and receiving electromagnetic waves. US patent application 2017/0317399 illustrates an electrically heatable window with an antenna. The antenna is fed at two locations with a top feed directly connected to a heatable coating while the bottom feed is capacitive coupled to a heating panel. However,

improvements to these antenna are needed to meet advancing antenna performance demands for antenna gain, radiation pattern and antenna impedance characteristics.

With rapid development of vehicle electronics, more and more antennas have been required for vehicles. At FM and TV frequencies in particular, vehicle systems require a number of antennas for diversity operation to overcome multipath and fading effects. Currently, in most cases separate antenna and antenna feeds are used to meet the requirements of AM, FM, TV, weather Band, Remote Keyless Entry, and DAB Band III frequencies. Most of those are integrated into back window glass. Multiple coaxial cables running from the antenna to the receiver can be avoided by combining the separate antenna signals using an electrical network. Such a network, however, involves the added complexity and expense of a separate module. In order to limit complexity and expense of an on-glass antenna system, the number of antenna feeds should be limited. Therefore, it would be advantageous to provide an antenna, particularly an electrically heatable IR reflective hidden window antenna, with multiple frequency bands for different applications.

An objective of the present invention is to reduce number of antennas on the vehicle to simplify the antenna and associated electronics design through advanced antenna matching and frequency tuning methods. Preferably, the antenna meets system performance requirements while retaining all solar benefits of the heat reflective coating and excellent aesthetics.

SUMMARY OF THE INVENTION

The presently disclosed invention discloses a slot antenna that is suitable for use in vehicle applications. The disclosed antenna with a plurality of antenna feed methods has improved impedance matching and frequency tuning capability. The slot antenna affords improved performance in the VHF and UHF bands while also retaining the solar benefits of the heat reflective coating, window heating capability for defrosting, deicing, or defogging and excellent aesthetics.

The slot antenna is formed between the metal frame of a window and a layer of conductive transparent film or coating that is bonded to the window glazing. Two side edges of the coating are connected to high conductive buses that are connected to an external circuit. When a DC voltage is applied through the buses to the coating, an electric current flows through the conductive, transparent film and across the window to heat the window. When no electrical current moves through the coating, the coating functions as a solar control coating. Two conductive buses and the coating define an outer peripheral edge that is spaced from the inner edge of the window frame to form a slot antenna. The slot dimension is designed to support fundamental and higher order modes within frequency bands of interest. Preferably, the total slot length of an annular shaped slot is one wavelength for the fundamental excitation mode and two wavelengths for the first higher order excitation mode.

The slot antenna can be excited by a voltage source such as a balanced parallel transmission line that is connected to the opposite edges of the slot, or by a coaxial transmission line that is connected to the opposite edges of the slot. The slot antenna may also be fed by a coplanar line probe. In the coplanar line probe the inner conductor is extended along the center of the slot to form a coplanar transmission line, effectively giving a capacitive voltage feed. Energy applied to the slot antenna causes electrical current flow in the conductive coating, heating buses, and metal frame of the window. The electrical currents are not confined to the edges of the slot, but rather spread out over the conductive sheet and heating buses. Radiation then occurs from the edges and both sides of the conductive sheets and heating buses.

For a typical sedan car, the slot length on the rear window has first higher mode resonant at FM frequencies (76 MHz-108 MHz). For a car with a larger back window, the resonant frequency may be in the lower half of the FM frequency band. In order to move the first higher mode to resonate at the center of the FM band, part of the perimeter edge of the conductive coating is extended outwardly so that it overlays the edge of the window frame. This overlay is longitudinally located along the slot at a "null" location of the electrical field to minimize the loading effect on the first higher mode. The overlay of the extended coating edge and the edge of the window frame causes a short of the coating to the window frame through capacitive coupling. The resonant frequency of the first higher mode is shifted higher because the total length of the slot is reduced by the shorting of the coating to electrical ground. By adjusting the longitudinal position of the overlap along the slot and adjusting the dimension between the coating edge and the edge of the window frame, the resonant frequency of the first higher mode can be tuned to the center of the FM band for better antenna performance.

The resonant frequency of the first higher mode can also be tuned higher by separating the electrically conductive IR coating into two coating panels with the lower coating panel overlapping the window frame near the bottom of the glazing. This causes the bottom coating panel to be electrically grounded to the frame though capacitive coupling. The annular slot is then formed around the perimeter of top coating panel only, i.e. between the coating panel edge and window frame on the top and sides of the upper coating panel and between the bottom edge of upper coating panel and top edge of lower coating panel. Resonant frequency of the slot mode is shifted higher due to the reduced total slot length. Relative size of the two coating panels can be adjusted for tuning the resonant mode frequencies.

Antenna for the AM frequency (150 KHz-1710 KHz) is sensitive to electronic noise. Sources of such noise include the window heating circuit, break lights, signal turning lights and fan motors. The AM antenna has to be separated from the coating panel to reduce low frequency noise generated from electrical current on the coating when powered by a DC source. It is also necessary to space the AM antenna away from the edge of the window frame because the coupling capacitance between the AM antenna and ground reduces antenna sensitivity. Given limitations on space around the slot, the AM antenna may not meet performance requirements. A piece of coating on the top or bottom can be isolated from the heating panel and used as an AM antenna. In general, the AM antenna performs better when the antenna is located near the top of the window.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the disclosed invention, reference should now be had to the embodiments illustrated in greater detail in the accompanying drawings and described below by way of examples of the invention. In the drawings:

FIG. **1** is a diagram of a glazing incorporating features of the presently disclosed invention;

FIG. **2** is sectional view taken along line A-A in FIG. **1**;

FIG. **3** illustrates an electrical field distribution of fundamental mode for a window antenna;

FIG. **4** illustrates an electrical field distribution of first higher mode for a window antenna;

FIG. **5** illustrates an electrical field distribution of first higher mode for a window antenna with four shorting strips;

FIG. **6** is a diagram of a glazing in which a shorting strip is located near the bottom center of the glazing;

FIG. **7** is a diagram of a glazing in which the reflective coating panel is separated into two panels with portions of the bottom panel overlapping the window frame;

FIG. **8** is a diagram of a glazing in which a separate AM antenna is located near the top of the glazing;

FIG. **9** is a diagram of a glazing in which a separate AM antenna is located near the bottom of the glazing;

FIG. **10** is plot of the antenna return loss of antenna on left side of the glazing illustrating the antenna resonant frequency bands from 50 MHz to 800 MHz.

FIG. **11** is plot of the antenna return loss of antenna on right side of the glazing illustrating the antenna resonant frequency bands from 50 MHz to 800 MHz.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a plan view of antenna backlight **10** and associated structure incorporating features of the presently disclosed invention. A glazing **20** is surrounded by a metal frame that has a window aperture that is defined by window edge **32** of a body **30**. The outer edge **40** of glazing **20** overlaps an annular flange formed by electrically conductive body **30** to provide, in this embodiment, a back window for the vehicle.

In the embodiment of FIGS. **1** and **2**, glazing **20** is a laminated glazing that includes an inner transparent ply **46** and an outer transparent ply **48** that may be composed of glass. Inner ply **46** and outer ply **48** are bonded together by an interlayer **50**. Preferably, interlayer **50** is made of polyvinylbutyral or similar material. Outer ply **48** has an outer surface **52** (conventionally referred to as the number **1** surface) that defines the outside of glazing **20** and an inner surface **54** (conventionally referred to as the number **2** surface). Inner surface **54** is oppositely disposed on outer ply **48** from outer surface **52**. Inner ply **46** has an outer surface **56** (conventionally referred to as the number **3** surface) that faces internally on glazing **20** and an inner surface **58** (conventionally referred to as the number **4** surface) that defines the inside of glazing **20** and faces internally to the vehicle. Interlayer **50** defines an outer surface **60** that faces surface **54** of outer ply **48** and an inner surface **62** that is oppositely disposed on interlayer **50** from outer surface **60** and that faces surface **56** of inner ply **46**. Backlite **10** is a laminated vehicle window formed of outer and inner glass plies **48** and **46**.

As shown in FIG. **2**, glazing **20** may include a concealment band **64** such as a paint band that is applied to outer ply **48** by screen printing opaque ink around the perimeter of surface **54** of outer ply **48** and then firing the perimeter of the outer ply. Concealment band **64** has a closed inner edge **66** that defines the boundary of the daylight opening (DLO) of glazing **20**. Concealment band **64** is sufficiently wide to cover the antenna elements of the disclosed backlite as well as other apparatus that is included near the outer perimeter of glazing **20** as hereinafter shown and described.

Glazing **20** further includes an electro-conductive coating **68** that covers the daylight opening of glazing **20**. Electro-conductive coating **68** reflects incident infrared solar radiation to provide a solar shield for the vehicle on which glazing **20** is used. Coating **68** reduces transmission of infrared and ultraviolet radiation through the glazing. Preferably, coating **68** is a semi-transparent electro-conductive coating that is applied on surface **54** of outer ply **48** (as shown in FIG. **2**) or on surface **56** of inner ply **46** in accordance with processes well known in the art. Coating **68** is electrically conductive and may have single or multiple layers of metal-containing coating as, for example, disclosed in U.S. Pat. No. 3,655,545 to Gillery et al.; U.S. Pat. No. 3,962,488 to Gillery and U.S. Pat. No. 4,898,789 to Finley. Typically, coating **68** has a sheet resistance in the range of 1Ω/□ to 3Ω/□ and an optical transmission of about 75%.

A band of coating **68** is removed from surface **54** of outer ply **48** between outer perimeter **40** of glazing **20** and a deletion edge **72** of coating **68** to form a band **70**. Coating **68** may be removed from glazing **20** either by mask deletion or laser deletion techniques. Removal of coating **68** in this way helps prevent corrosion at the perimeter of coating **68** and improves radio frequency transmission through glazing **20**. Deletion edge **72** is laterally located on glazing **20** between the inner edge **66** of band **64** and perimeter edge **40** of glazing **20**. Removal of coating **68** in this way provides the basic structure of an antenna slot when glazing **20** is received by conductive body **30** to cover the window aperture that is defined by window edge **32**.

A high conductive heating bus **76***a* and **76***b* is screen printed onto a portion of concealment band **64** covering surface **54** of outer ply **48** and a portion of surface **78** of coating **68** such that heating bus **76***a* and **76***b* each cover a longitudinal segment of deletion edge **72** of conductive coating **68**. Each of heating bus **76***a* and **76***b* overlays a portion of concealment band **64** and outer ply **48** that is adjacent deletion edge **72** and also overlays a portion of coating **68** that is adjacent deletion edge **72** such that each of heating bus **76***a* and **76***b* overlays a respective longitudinal segment of deletion edge **72**. Within the respective segment of deletion edge **72** that heating bus **76***a* and **76***b* overlay, heating bus **76***a* and **76***b* also respectively overlay the surface of band **70** that is laterally adjacent deletion edge **72** of coating **68**. In this way, heating bus **76***a* and **76***b* form respective metal strips that are electrically connected to coating **68** with a surface **80***a* of heating bus **76***a* contacting coating **68** and band **64** and a surface **80***b* of heating bus **76***b* also contacting coating **68** and band **64**. Heating bus **76***a* cooperates with the electrically conducting member or body **30** and with the electrically conductive coating **68** to define a slot antenna between the edge **34***a* of the heating bus **76***a*, edge **72** of conductive coating **68** and peripheral edge **32** of electrically conducting body **30**. Heating bus **76***b* cooperates with the electrically conducting member or body **30** and with the electrically conductive coating **68** to define a slot antenna between edge **34***b* of heating bus **76***b*, edge **72** of conductive coating **68**, and peripheral edge **32** of the electrically conducive body **30**.

Glazing **20** further includes a pair of flat conductive leads **80** and **82**. One end of lead **80** is electrically connected to heating bus **76***a* by a solder member **88***a*. One end of lead **82** is electrically connected to heating bus **76***b* by a solder member **88***b*. The respective other end of conductive leads **80** and **82** can be electrically connected to opposite terminals of an external DC power source (not shown) to apply an electrical voltage between heating bus **76***a* and heating bus **76***b*. Electrical current flowing through metallic coating **68** in response to the voltage applied between heating buses **76***a* and **76***b* generates heat on outer ply **48** of the back window for de-frost or de-ice purposes. Preferably, flat conductive leads **80** and **82** are covered by plastic tape **84** and **86** or other electrical insulation so that it is electrically isolated from window frame or body **30** and does not short out the DC voltage at locations where it passes the window frame surface.

Glazing **20** and its associated body structures define an annular antenna slot **70** between the window frame edge **32** on one side and the heating bus edges **34***a* and **34***b* in combination with coating edge **72** of conductive coating **68** on the other side. The slot width must be sufficiently large that the capacitive effects across it at the frequency of operation are negligible so that the signal is not shorted out. The slot width is preferably greater than 10 mm. The preferred length of the slot for an annular shaped slot is an integer multiple of wavelength at the resonant frequency of application. The preferred length of the slot for a non-annular shaped slot is an integer multiple of one half of the wavelength with respect to resonant frequency of application. For a backlite **10** of a typical vehicle, the slot length is such as to resonate at fundamental mode and at first higher mode at the VHF band and also is useful for the TV VHF band and FM applications.

FIG. **3** illustrates the field distribution of the fundamental mode with a maximum field strength (open) at the center of the top and bottom sides of the slot and a minimum field strength (short) at middle of the right and left sides of the slot. FIG. **4** shows the field distribution of the first higher mode which has a maximum field strength (open) at the corners of the slot and a minimum field strength (short) at middle of the slot at each of the top, bottom, right and left sides. The heating conductive leads **80** and **82** that connect to a DC power supply must be placed across the slot. If they are placed symmetrically in the middle of the right and left slot sides as shown in FIG. **3** and FIG. **4**, the conductive leads **80** and **82** cross the slot at "short" points of both the fundamental mode and the first higher mode so that the fundamental mode and the first higher mode can be excited without significantly loading those modes from conductive leads **80** and **82**. At times when no heating function is needed or when the heating leads **80** and **82** can be made to have high impedance by connecting to RF chocks, the "short" and "open" locations of the modes can be located in various longitudinal positions depending on the slot antenna feeding position and feeding conditions.

The slot antenna can be excited by a voltage source such as a balanced parallel transmission line that is connected to the opposite edges of the slot or by a coaxial transmission line that is connected to the opposite edges of the slot. FIG. **3** and FIG. **4** illustrate that the fundamental mode has a maximum near the center of the top and bottom sides of the slot, while the first higher mode has a minimum near the center of all four sides of the slot. Hence, feeding the slot antenna near the center position of the top or bottom sides with a voltage probe will excite only the fundamental mode. Placing the feed between minimum field strength positions of the first higher mode (e.g. at the corners) will excite both the fundamental and first higher order modes. The radiation pattern will differ depending on the particular combination of modes that is excited. At higher frequencies the slot is effectively longer and hence more than one mode can be excited from feed positions that are λ/4 apart.

The resonant frequencies of the antenna fundamental mode and first higher mode are determined predominantly by the slot length which can be designed such that the antenna mode resonant frequencies coincide with the operation frequencies of typical vehicle electronics systems. For vehicles with large windows, the resonant frequencies of the slot antenna may be too low for such applications. In that case, the slot length can be shortened by overlapping the edge **32** of the vehicle frame **30** by one or more portions of the conductive coating **68** at locations near 'short' positions of the field strength. This is illustrated in FIG. **5** with four 'short' positions where portions of the peripheral edge of coating **68** are extended outwardly to overlap a liner segment (i.e. a portion of) window edge **32** at respective locations where the field strength minimums (i.e. "shorts") of the first higher order mode are located. FIG. **6** illustrates a window slot antenna that has a longer shorting overlap at a 'short' position near the bottom center for comparison to the linear segments of overlap that are illustrated in FIG. **5**. Overlapping between coating **68** and window edge **32** as illustrated in FIGS. **5** and **6** causes the radio frequency signal to short to the vehicle frame through capacitive coupling. Because the overlapping occurs at 'short' positions for the first higher mode, it doesn't significantly load the slot antenna mode. However, because the overlapping is at the maximum field location (i.e. "open") for the fundamental mode, the fundamental mode is suppressed. For the first higher mode, the field distribution remains substantially the same along the slot antenna, but with shorter slot length. Selective overlapping by coating **68** in this way affords a technique for tuning the slot antenna to higher frequency bands for more precise antenna matching. In this way, window antennas in accordance with the disclosed invention can tune the antenna resonant frequency higher to accommodate the vehicle electronics system frequencies.

As illustrated in FIG. **7**, the resonant frequency of the first higher mode can also be tuned higher by separating coating **68** into an upper coating panel **68***a* and a lower coating panel **68***b* that are separated by a slot **68***c* in which there is no electrically conductive coating. The bottom edge of lower coating panel **68***b* is extended to overlap the edge **32** of the window frame such that coating panel **68***b* is electrically grounded along the bottom edge to the window frame through capacitive coupling. An annular slot is formed only around the perimeter of coating panel **68***a*, i.e. between the window frame **30** and edges of coating panel **68***a* along the top and sides and along the slot between coating panel **68***a* and **68***b*. Resonant frequency of the slot mode is shifted higher in comparison to the slots of FIGS. **1** and **3** due to the shorter total slot length. Relative size of the two coating panels can be varied to further adjust and tune resonant mode frequencies. As shown in FIG. **7**, two separate conductive leads **80** and **82** are required to connect to a DC power supply to heat the whole back window, i.e. panel **68***a* and panel **68***b* respectively.

The slot antenna can be excited by a voltage source such as a balanced parallel transmission line that is connected to the opposite edges of the slot, or by a coaxial transmission line that is connected to the opposite edges of the slot. As illustrated in FIG. **1**, antenna **92***a* is fed by a short antenna feed line that is orthogonal to the antenna slot and connected to antenna pad and heating bus **76***a* from the side of the glazing to define the antenna feed point. A flat antenna connector (not shown) connects to the antenna pad at the feed point and then connects the antenna to an external module. At the feed point, the antenna feed voltage is equal to the aperture field voltage of the slot antenna at the longitudinal position of the feed point. Referring to the field distributions illustrated in FIG. **3** and FIG. **4**, at antenna feed point **92***a* both fundamental mode and first higher mode can be excited because the longitudinal position of the feed point **92***a* along the slot is near maximum field strength (i.e. "open") for the first higher mode and away from the minimum field (i.e. "short") for the fundamental mode. The same is true for antenna **94***a* which is located at the glazing corner at the opposite side from antenna **92***a*. Antennas **92***a* and **94***a* are a quarter of wavelength apart for the fundamental mode so they are weakly coupled. Antenna **92***a* and **94***a* are also half wavelength apart at the first higher mode and therefore isolated from each other at the first higher order mode. Thus, they can be used simultaneously for a diversity antenna system. At UHF band, the higher order modes may be excited at various points a quarter wavelength apart to generate different antenna patterns, thus establishing pattern diversity. Antenna **92***a* and **94***a* have been designed for wideband applications for FM from 76 MHz to 108 MHz, DAB from 174 MHz to 240 MHz and TV UHF band from 470 MHz to 760 MHz. That requires the slot antenna to be excited for fundamental and first higher modes for FM and for higher order modes for DAB and TV frequencies.

The disclosed slot antenna can also be fed by a coupled coplanar line as shown in FIG. **1**. Antenna **98** includes a coplanar line **102** that does not connect to the heating bus **76***b* or coating **68** so that coplanar line **102** effectively provides a capacitive voltage feed. Since coplanar line **102** is a distributed feed, coplanar line **102** may cross excitation points for both fundamental and higher order modes. Excitation of higher order modes is desirable for high frequency and multiband antenna applications such as TV antenna or antennas with multiple frequency bands.

An embodiment similar to that illustrated in FIG. **1** with a voltage probe feed and a coupled coplanar line feed was constructed and tested on a vehicle. The dotted line in FIG. **10** and FIG. **11** shows the plot of the return loss (S**11**) of the slot antenna **92***a* and **94***a* respectively. Return loss is a measure of the power delivered to the antenna and reflected from the antenna verses the power that is "accepted" by the antenna and radiated. FIG. **10** and FIG. **11** show that the antenna resonates well in multiple frequency bands from 50 MHz up to 800 MHZ which covers FM/TV band II (76-108 MHz), TV band III (174 MHz-230 MHz), digital audio broadcasting (DAB III) (174 MHz-240 MHz), TV band IV and V (474 MHz-760 MHz). However, the FM band (76 MHz-108 MHz) is not fully covered by the antennas **92***a* and **94***a*. To improve antenna matching in the higher portions of the FM band, the conductive coating near the bottom center of the glazing is extended so that it overlaps the edge of window frame **30** as shown in FIG. **6**. Overlapping the conductive coating and window frame edge in this way shorts the radio frequency signal to the vehicle frame through capacitive coupling. Because the overlapping occurs at weaker field strength ("short") positions of the first higher mode, it doesn't significantly load the first higher order slot antenna mode. The field distribution remains substantially the same for the first higher order mode along the slot antenna, but with shorter slot length. This affords a way to tune the slot antenna to higher frequency bands for better antenna matching with typical vehicle modules. The solid line in FIG. **10** and FIG. **11** represents the plot of the return loss (S**11**) of the slot antenna **92***b* and **94***b* respectively when the conductive coating near the bottom center of the glazing overlaps the edge **32** of window frame **30**. FIGS. **10** and **11** show significant improvement in return loss in the FM band. Since the overlapping of coating **68** and window edge **32** applies primarily only to the first higher order mode (FM), all other modes maintain nearly the same response as shown in FIG. **10** and FIG. **11**. Results of far-field gain measurements show the antenna performs very well at all bands including FM, DAB and TV. The slot antenna demonstrates the capability for multi-band application which can reduce the required number of antennas, simplify antenna amplifier design, and reduce overall costs of the antenna system.

Antenna **96** as shown in FIG. **1** is intended for AM reception (150 KHZ-1710 KHZ). AM antenna **96** has to remain apart from window frame **30** to reduce shunt capacitance load which reduces antenna sensitivity. On the other hand AM antenna **96** is sensitive to electronic noise. Sources of such electronic noise include the window heating circuit, break lights, signal turning lights and fan motors. These constraints limit the location of AM antenna **96** to between coating edge **72** and the edge of window frame **32**. AM antenna **96** shown in FIG. **1** is composed of two portions. A first portion includes three horizontal lines **42** that are connected to a single line that is connected to an antenna connection pad. A second portion of AM antenna **96** is a vertical line **43** that is connected to the connection pad of AM antenna **96**. Depending on the glass size and slot width between conductive coating edge **72** and window frame edge **32**, the AM antenna may not meet certain performance requirements. To improve AM antenna performance, a portion of conductive coating **68** may be separated and used as an AM antenna as shown in FIG. **8**. FIG. **8** includes a conductive coating that is separated into an upper panel **102*a*** and a lower panel **103**. AM Antenna **100** includes a conductive trace **104** and antenna bus **106**. Antenna bus **106** is electrically connected to conductive coating **102*a*** which is the upper portion of conductive coating **68**. AM antenna is separated from the coating panel **103** with sufficient gap to reduce low frequency noises generated from electrical current on the coating when powered by a DC source. Laser deletion is preferred to separate the AM antenna. Laser deletion is less apparent visually and the size and pattern of the laser deletion window can be designed and precisely controlled to meet performance requirements. An AM antenna can also be constructed with the bottom portion of coating panel **68** isolated and connected to the AM antenna **96** as shown in FIG. **9**. In general, the AM antenna performs better when the antenna is located near the top of the glazing.

While the invention has been described and illustrated by reference to certain preferred embodiments and implementations, it should be understood that various modifications may be adopted without departing from the spirit of the invention or the scope of the following claims.

What is claimed is:

1. An antenna that is included in a window assembly that is receivable in a frame member that is electrically conductive and that has an edge that defines a window opening, said antenna comprising:

at least one ply having a surface that is defined by an outer perimeter edge;

an optically transparent electrically conductive coating that is located on the surface of said ply, said electrically conductive coating having an outer peripheral edge with at least a portion of said outer peripheral edge being spaced inwardly from the outer perimeter edge of said ply;

a first heating bus that has greater electrical conductivity than the electrical conductivity of said electrically conductive coating, said first heating bus being located partly on an edge of said electrically conductive coating and partly over the surface of said ply, said first heating bus having a first edge such that, at times when said window assembly is received in said frame member, said first edge of said first heating bus is spaced laterally between the outer peripheral edge of said electrically conductive coating and the edge of said frame member, said first heating bus cooperating with said frame member and with said electrically conductive coating to define a slot antenna;

a second heating bus that has greater electrical conductivity than the electrical conductivity of said electrically conductive coating, said second heating bus being located partly on an edge of said electrically conductive coating and partly over the surface of said ply, said second heating bus being located oppositely on said electrically conductive coating from said first heating bus and having a first edge such that, at times when said window assembly is received in said frame member, said first edge of said second heating bus is spaced laterally between the outer peripheral edge of said electrically conductive coating and the edge of said frame member, said second heating bus cooperating with said frame member and with said electrically conductive coating to define the slot antenna;

a first electrical conductor that electrically connects to said first heating bus and a second electrical conductor that electrically connects to said second heating bus, said first electrical conductor also being connectable to one terminal of a DC voltage source and said second electrical conductor also being connectable to a second terminal of said DC voltage source that has opposite electrical polarity from said first terminal so that at times when the first electrical conductor and the second electrical conductor are connected to the DC voltage source, an electric current flows through said electrically conductive coating to heat said ply; and

an antenna feed line that is located on said ply and that electrically connects to one of said first heating bus or said second heating bus.

2. The antenna of claim **1** wherein said first heating bus also has a second edge that is spaced laterally inwardly from the outer peripheral edge of said electrically conductive coating such that said first heating bus overlaps at least a partial length of the outer peripheral edge of said electrically conductive coating, and wherein said second heating bus also has a second edge that is spaced laterally inwardly from the outer peripheral edge of said electrically conductive coating such that said second heating bus overlaps at least a partial length of the outer peripheral edge of said electrically conductive coating.

3. The antenna of claim **2** wherein said first heating bus and said second heating bus cooperate with the peripheral edge of said electrically conductive coating to define one side of said slot antenna and wherein the edge of said frame member defines the opposite side of said slot antenna.

4. The antenna of claim **3** wherein said antenna feed line crosses the first edge of one of said first bus or said second heating bus and also crosses the edge of said frame member.

5. The antenna of claim **3** wherein accordance with the dimension and location of said antenna feed line, the location of said heating bus, the length of the slot antenna, the gap between the first edge of said first heating bus and the edge of said frame member, and the gap between the first edge of said second heating bus and the edge of said frame member determine the impedance of said slot antenna at different modes.

6. The antenna of claim **3** wherein said slot antenna is fed by a voltage probe or a coaxial cable with the outer conductor of said coaxial cable being connected to said frame member and the center conductor of said coaxial cable being connected to said feed line and also connected to said heating bus.

7. The antenna of claim 3 wherein said slot antenna is fed by a coupled coplanar line, said coupled coplanar line being laterally spaced between the first edge of said first heating bus and the edge of said frame member or between the first edge of said second heating bus and the edge of said frame member.

8. The antenna of claim 3 wherein said slot antenna has a fundamental mode with a maximum field strength located longitudinally along said slot antenna at the center of portions of said slot antenna that are oppositely disposed on said electrically conductive coating and wherein said first and second electrical conductors are longitudinally located along said slot antenna at locations of minimum field strength of said slot antenna.

9. The antenna of claim 3 wherein said slot antenna defines upper and lower sides that are connected by left and right sides, said upper and lower side cooperating with said left and right sides to form corners between said sides, said slot antenna having a first higher mode with a maximum field strength in the corners of said slot antenna and said first and second electrical conductors being longitudinally located along said slot antenna locations of at minimum field strength of said slot antenna.

10. The antenna of claim 9 wherein said optically transparent electrically conductive coating has a peripheral edge that partially overlaps said frame member at the longitudinal location of minimum field strength, said optically transparent electrically conductive coating being electrically connected to said frame member through capacitive coupling at said minimum field strength locations.

11. The antenna of claim 10 wherein the electrical connection of said optically transparent electrically conductive coating to said frame member at minimum field strength locations does not change field distribution along said slot antenna and wherein the slot length of said slot antenna is shortened through capacitive coupling to cause the resonant frequency of said slot antenna to shift higher.

12. The antenna of claim 3 wherein said antenna feed line is connectable to said antenna feed point at any location along said first heating bus or said second heating bus.

13. The antenna of claim 3 wherein said antenna feed line is located laterally between the first edge of said first heating bus or said second heating bus heating bus and the perimeter edge of said ply to define an antenna design.

14. The antenna of claim 13 wherein said window assembly includes a plurality of antenna designs, the antenna feed line for each respective antenna having a lateral location between the first edge of said first heating bus or said second heating bus and the perimeter edge of said ply to define the respective antenna design.

15. An antenna for use in a vehicle that includes an electrically conducting member having an inner edge that defines a window opening, said antenna comprising:

(a) a window assembly that is configured to be received over said window opening, said window assembly including:
 at least one transparent ply having a surface that is defined by an outer edge;
 an optically transparent electrically conductive coating that is located on the surface of said transparent ply, said electrically conductive coating having an outer peripheral edge with at least a portion of said outer peripheral edge being spaced laterally inwardly from the inner edge of the electrically conducting member of said vehicle;
 a heating bus that is located partially on the surface of said transparent ply, said heating bus having greater electrical conductivity than the electrical conductivity of said transparent electrically conductive coating, said heating bus having a first portion and a second portion with each of said first and second portions respectively having a first edge that is spaced laterally between the outer peripheral edge of said electrically conductive coating and the inner edge of the electrically conducting member of said vehicle, each of said first and second portions of said heating bus also respectively having a second edge with at least a portion of said second edge being laterally spaced inwardly from the outer peripheral edge of said electrically conductive coating and over said electrically conductive coating such that said portion of said heating bus overlaps at least a portion of the outer peripheral edge of said electrically conductive coating, said heating bus cooperating with said electrically conducting member and with said electrically conductive coating to define a slot antenna between the first edge of said heating bus and the inner edge of said electrically conducting member;
 an antenna feed line that is located on said transparent ply between the first edge of said heating bus and the inner edge of said electrically conducting member; and
 an antenna feed point that electrically connects said antenna feed line to said heating bus;
(b) a first heating wire that is electrically connected to the first portion of said heating bus at the midpoint between opposite ends of said first portion of said heating bus and a second heating wire that is electrically connected to the second portion of said heating bus at the midpoint between opposite ends of the said second portion of said heating bus;
(c) an antenna feed cable that is electrically connected to said antenna feed line; and
(d) an electrical ground between said antenna feed cable and the electrically conducting member of said vehicle.

16. The antenna of claim 15 further comprising a band of opaque coating around the perimeter of the window assembly, said antenna feed being located laterally within the width of said band of opaque coating.

17. The antenna of claim 15 wherein said slot antenna has a slot width that is sufficient to negate capacitive effects across the slot antenna at the operation frequencies.

18. The antenna of claim 15 wherein the antenna feed point of said window assembly comprises an electrically conductive line that is connected to the antenna feed line and to the heating bus.

19. The antenna of claim 15 wherein said heating bus is electrically connected to said electrically conductive coating.

20. The antenna of claim 15 wherein said slot antenna has an annular configuration and the slot length of said slot antenna is one wavelength at the fundamental excitation mode.

21. The antenna of claim 15 wherein said slot antenna has an annular configuration and the slot length of said slot antenna is two wavelengths at the first higher excitation mode.

22. The antenna of claim 15 wherein said slot antenna defines an upper portion and a lower portion that are connected on respective ends by a left side portion and that are connected on opposite respective ends by a right side portion, said fundamental mode having a maximum field strength in the center of the upper portion of said slot

antenna and in the center of the lower portion of said slot antenna, and wherein said first and second heating wires cross said slot antenna at respective minimum field strength locations.

23. The antenna of claim **22** wherein said upper and lower portions of said slot antenna cooperate with said left and right portions of said slot antenna to define corners of said slot antenna between said left portion and said upper and lower portions and between said right portion and said upper and lower portions, a first higher mode having a maximum field strength in the corners of said slot antenna and said heating wire crossing said slot antenna at the location of minimum field strength.

24. The antenna of claim **15** wherein said optically transparent electrically conductive coating has a peripheral edge partially overlaps said frame member at longitudinal locations of minimum field strength of said first higher mode, said optically transparent electrically conductive coating being electrically connected to the said frame member through capacitive coupling at the location of said minimum field strength.

25. The antenna of claim **24** wherein said optically transparent electrically conductive coating is electrically connected to said frame member at longitudinal locations of minimum field strength wherein such electrical connection does not change field distribution of said slot antenna even though the effective slot length of said slot antenna is shortened such that the resonant frequency of said slot antenna is shifted higher for more closely match the antenna in the FM, DAB or TV frequency bands.

26. The antenna of claim **25** wherein said slot antenna can be fed by a voltage probe or by a coaxial cable with the outer conductor of said coaxial cable being connected to said conductive member of said vehicle and the center conductor of said coaxial cable being connected to said feed line and said heating bus.

27. The antenna of claim **26** wherein said voltage probe crosses voltage excitation points for fundamental and higher order modes, the excitation of higher order modes being desirable for high frequency and multiband antenna applications including FM, DAB, TV antenna or antennas with more than one frequency band.

28. The antenna of claim **15** wherein said slot antenna is fed by a coupled coplanar line that is laterally spaced between the first edge of said heating bus and the edge of said conductive frame of said vehicle.

29. The antenna of claim **28** wherein the dimensions of said coupled coplanar line are selected to match the slot antenna impedance to the impedance of an input device.

30. The antenna of claim **29** wherein said probe voltage and coupled coplanar line are configured to feed the antenna at pre-selected longitudinal positions on the perimeter of said window assembly.

31. The antenna of claim **28** wherein said coupled coplanar line slot antenna feed excites both the fundamental mode and higher-order modes in the VHF and UHF bands for multiband applications.

32. The antenna of claim **15** wherein said slot antenna has a single feed and is operative in a frequency band from 76 MHz to 108 MHz for FM, 174 MHz to 240 MHz for DAB, 470 MHz to 760 MHz for TV applications.

33. The antenna of claim **15** wherein said slot antenna is fed from multiple voltage probes and coplanar feed lines that are respectively located at different longitudinal positions on said slot antenna to provide an antenna diversity system that excites different modes of the slot antenna to provide different respective field distributions.

34. The antenna of claim **15** wherein said optically transparent electrically conductive coating is electrically separated into top and bottom panels with the periphery edge of said bottom panel extending to overlap the edge of said frame member, said overlapping of the electrically conductive bottom panel and said frame member forming an electrical ground connection.

35. The antenna of claim **34** wherein said top panel has a shorter periphery edge in comparison to the periphery edge of the top and bottom conductive coating panels Such that the resonant frequency of said slot antenna is shifted to higher frequencies that more closely match FM, DAB or TV frequencies.

36. The antenna of claim **34** wherein the area of said top panel or said bottom panel is selected for use as an AM antenna.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 10,847,867 B2
APPLICATION NO. : 16/292691
DATED : November 24, 2020
INVENTOR(S) : David Dai

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

At Column 10, Line 24, in Claim 1:
Delete "one terminal", and insert --a first terminal--, therefor.

At Column 10, Line 47, in Claim 3:
Delete "the peripheral", and insert --the outer peripheral--, therefor.

At Column 10, Line 52, in Claim 4:
Delete "said first bus", and insert --said first heating bus--, therefor.

At Column 10, Line 54, in Claim 5:
Delete "wherein accordance with the", and insert --wherein the--, therefor.

At Column 10, Line 56, in Claim 5:
Delete "said heating bus", and insert --said first heating bus or said second heating bus--, therefor.

At Column 10, Lines 56-58, in Claim 5:
Delete "the gap between the first edge of said first heating bus and the edge of said frame member", and insert --a gap between the first edge of said first heating bus and the edge of said frame member--, therefor.

At Column 10, Lines 58-60, in Claim 5:
Delete "the gap between the first edge of said second heating bus and the edge of said frame member", and insert --a gap between the first edge of said second heating bus and the edge of said frame member--, therefor.

At Column 10, Line 66, in Claim 6:
Delete "said feed line", and insert --said antenna feed line--, therefor.

Signed and Sealed this
Twenty-third Day of November, 2021

Drew Hirshfeld
Performing the Functions and Duties of the
Under Secretary of Commerce for Intellectual Property and
Director of the United States Patent and Trademark Office

At Column 10, Lines 66-67, in Claim 6:
Delete “said heating bus”, and insert --said first heating bus or said second heating bus--, therefor.

At Column 11, Line 17, in Claim 9:
Delete “said upper and lower side”, and insert --said upper and lower sides--, therefor.

At Column 11, Line 18, in Claim 9:
Delete “said sides”, and insert --two adjacent sides--, therefor.

At Column 11, Line 38, in Claim 12:
Delete “said antenna feed point”, and insert --an antenna feed point--, therefor.

At Column 11, Lines 43-44, in Claim 13:
Delete “the perimeter edge”, and insert --the outer perimeter edge--, therefor.

At Column 11, Line 49, in Claim 14:
Delete “the perimeter edge”, and insert --the outer perimeter edge--, therefor.

At Column 12, Lines 30-31, in Claim 15:
Delete “the midpoint between opposite ends of said first portion”, and insert --a midpoint between opposite ends of said first portion--, therefor.

At Column 12, Lines 33-34, in Claim 15:
Delete “the midpoint between opposite ends of the said second portion”, and insert --a midpoint between opposite ends of said second portion--, therefor.

At Column 12, Line 42, in Claim 16:
Delete “said antenna feed”, and insert --said antenna feed line--, therefor.

At Column 12, Line 66, in Claim 22:
Delete “said fundamental mode”, and insert --a fundamental excitation mode of said slot antenna--, therefor.

At Column 13, Lines 11-12, in Claim 23:
Delete “said heating wire”, and insert --said first heating wire or said second heating wire--, therefor.

At Column 13, Line 14, in Claim 24:
Delete “The antenna of claim 15”, and insert --The antenna of claim 23--, therefor.

At Column 13, Line 16, in Claim 24:
Delete “said frame member”, and insert --said electrically conducting member--, therefor.

At Column 13, Lines 17-18, in Claim 24:
Delete “said first higher mode”, and insert --a first higher excitation mode of the fundamental mode of said slot antenna--, therefor.

At Column 13, Lines 19-20, in Claim 24:
Delete "said frame member", and insert --said electrically conducting member--, therefor.

At Column 13, Line 24, in Claim 25:
Delete "said frame member", and insert --said electrically conducting member--, therefor.

At Column 13, Lines 33-34, in Claim 26:
Delete "said conductive member", and insert --said electrically conducting member--, therefor.

At Column 13, Line 35, in Claim 26:
Delete "said feed line", and insert --said antenna feed line--, therefor.

At Column 13, Line 41, in Claim 27:
Delete "FM, DAB, TV antenna", and insert --FM, DAB, or TV antenna--, therefor.

At Column 14, Line 1 in Claim 28:
Delete "The antenna of Claim 15", and insert --The antenna of Claim 27--, therefore.

At Column 14, Lines 3-4, in Claim 28:
Delete "the edge of said conductive frame", and insert --an edge of said electrically conducting member--, therefor.

At Column 14, Lines 8-9, in Claim 30:
Delete "said probe voltage and coupled coplanar", and insert --said voltage probe and said coupled coplanar--, therefor.

At Column 14, Lines 12-13, in Claim 31:
Delete "said coupled coplanar line slot antenna feed excites", and insert --said coupled coplanar line excites--, therefor.

At Column 14, Lines 29-30, in Claim 34:
Delete "the edge of said frame member", and insert --an edge of said electrically conducting member--, therefor.

At Column 14, Lines 30-31, in Claim 34:
Delete "the electrically conductive bottom panel and said frame member forming", and insert --the bottom panel and said electrically conducting member forming--, therefor.

At Column 14, Line 35, in Claim 35:
Delete "and bottom conductive coating panels Such that", and insert --and bottom panels such that--, therefor.